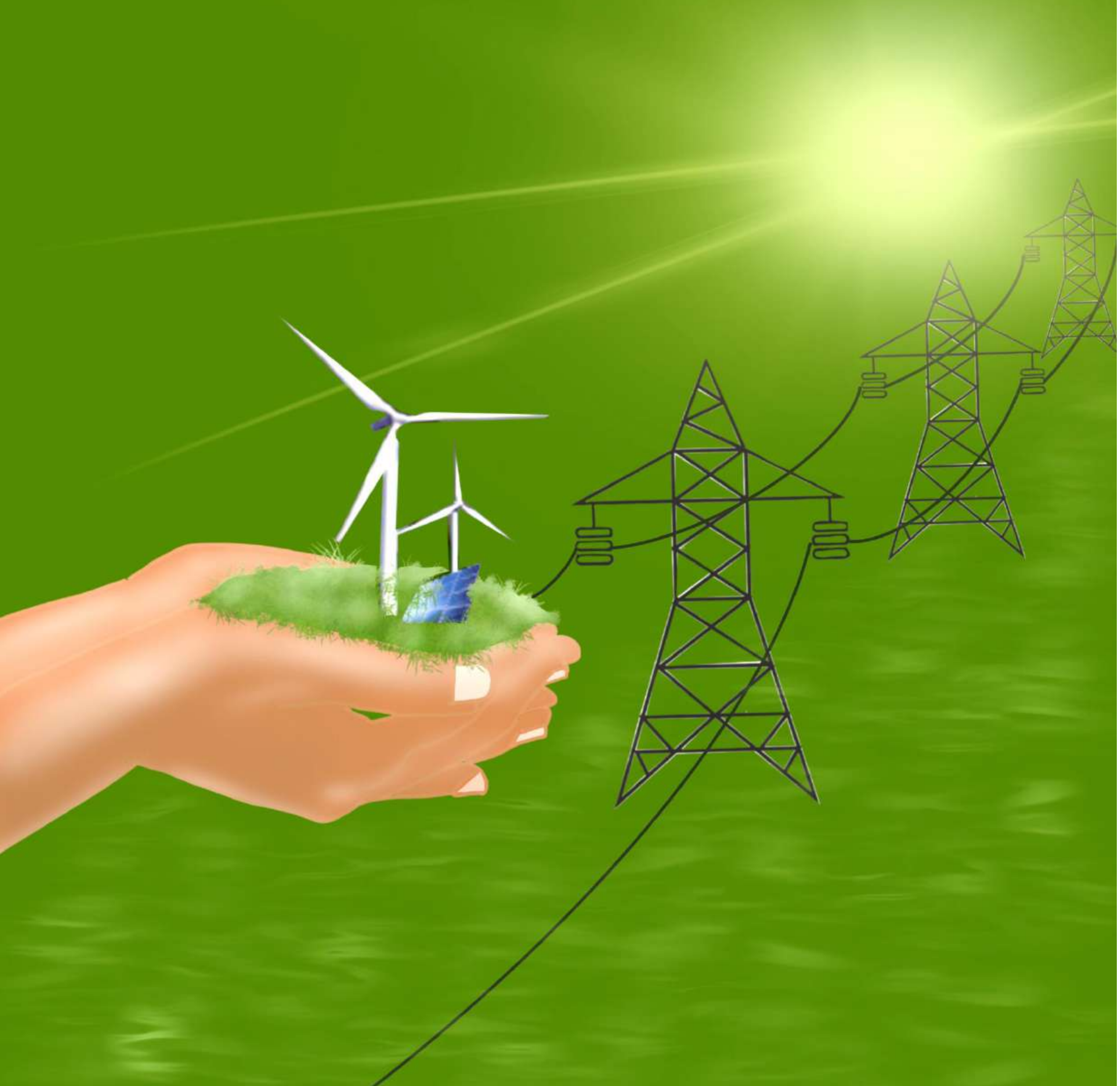
Rolling Plan 2026-27

Inter-State Transmission System (ISTS)



March 2022

Central Transmission Utility (CTU)

Table of Contents

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List of Figures

List of Tables

Executive Summary

Today, India is on the path of high economic growth and is aiming to be a 5 trillion USD economy in coming years. Electricity sector is playing a very vital role in this economic development by acting as a secure and reliable source of energy. One of the emerging utilisations of electricity today is in the transportation sector with Central and State Governments promoting faster adoption of Electric Vehicles (EVs), to reduce emission of greenhouse gases. To meet the growing energy demand in sustainable and eco-friendly manner, India is going through a phase of energy transition at rapid pace with greater focus on development of new Renewable Energy (RE) resources. In this direction, at the COP26 climate conference in Glasgow, India has committed to achieve non-fossil energy capacity of 500GW by 2030 and to meet 50 per cent of its energy requirement through RE by 2030. Further, India has also set target of being a net zero emitter by 2070.

Now, large RE parks of GW capacities are being developed in the country in resources rich areas to meet the energy transitions goals. This huge quantum of RE needs to be transferred reliably and securely to all the major load centres of the country, which necessitates development of robust National Grid comprising of high capacity AC and HVDC systems along with state-of-the-art FACTS devices for controlling power system parameters. India's path and ways of RE integration to its National Grid can act as blue print for other countries for development of new age electricity grid. There is also a thrust on development and integration of Energy Storage devices in form of batteries, pumped hydro etc. in the National Grid, for providing balancing power during low or no RE period and also increasing utilisation of transmission system associated with RE projects.

Transmission system is acting as a growth engine of electricity sector and therefore should be planned and developed adequately so as enable seamless integration of generation projects and also facilitate availability of reliable, secure, and affordable power to all the consumers. In this direction, Ministry of Power, Govt. of India vide gazette notification dated 01st Oct 2021, has notified Electricity (Transmission System Planning, Development and Recovery of Inter-State Transmission Charges) Rules, 2021. As per the said rules CTU has to draw up plan for Inter-State Transmission System (ISTS) for up to next five years on rolling basis every year identifying specific transmission projects which are required to be taken up along with their implementation time lines. Accordingly, an ISTS Planning Procedure has been prepared and published by CTU on 16th Dec 2021 for the purpose of planning and coordination relating to ISTS. The entire process for transmission planning has been decided to be undertaken on continuous basis, involving two cycles i.e. from April to September and October to March. Thus, Network Plan reports would be brought out by CTU on half-yearly basis in the months of September and March in every financial year. In this direction, a report on Network Plan 2024-25 has already been brought out on 31st Dec 2021 and the same is available on CTU website. Further, this ISTS Rolling Plan report is being brought out wherein transmission system adequacy in ISTS has been assessed for 2026-27 time-frame.

In **Chapter-2**, installed capacity & peak demand as on Jan'22 and projected installed capacity & demand by FY 2026-27 have been presented. All India installed capacity & peak demand are expected to increase from 395GW (including about 106GW RE + 47GW Hydro) & 203GW respectively as on Jan'22 to about 568GW (including about 225GW RE + 71GW Hydro) & 299GW respectively by FY 2026-27.

In order to integrate the envisaged generation capacity, predominantly RE, and to meet the projected demand, comprehensive studies have been performed on the National Grid on All India and Regional basis for planning and development of Inter-State Transmission System (ISTS). To perform the studies, Load Generation Balance (LGB) has been prepared considering the diurnal and seasonal load and generation variations across the country. Accordingly, nine number of load-generation scenarios have been identified corresponding to Monsoon, Summer, and Winter seasons along with three points on daily load curve for each season viz. Solar max, Peak demand, and Off-peak demand.

Detailed overview of the load generation balance preparation and challenges observed while balancing the same and study results have been brought out in **Chapter-3**. While preparing LGB for nine scenarios, merit order economic dispatch of thermal generations and RPO obligations of states have been taken into consideration. Maximum and minimum demand of 299GW and 191GW respectively have been considered in 2026-27 timeframe while working out the LGBs.

Detailed system studies have been carried out for nine scenarios using PSS®E software after considering all the planned and under construction system, in line with provisions under CEA's Manual on Transmission Planning Criteria. Due to intermittent and variable nature of RE and with high penetration of RE in the Indian Grid, loading pattern on some of the lines is expected to change diurnally as well as seasonally. Further, transmission lines associated with thermal and hydro generations would be lightly loaded during high RE scenario. In the Chapter-3, study results have been presented for All India grid (above 400kV) including critically loaded lines & transformers under normal & N-1 condition, voltage violations, short circuit violations etc. Network expansion schemes have been planned and being planned to take care of the observed system violations. Accordingly, year on year progressive addition of transmission system in ISTS network in terms of new transmission lines (ckm) and substations (MVA) upto 2026-27, and its corresponding broad estimated cost has also been brought out in the report. In this Rolling Plan, transmission schems of about 3,772 ckm of transmission lines and 32,490 MVA of transformation capacity has been formulated at an estimated cost of Rs.14,646 Cr. Thus, cumulatively by 2026-27, transmission schemes comprising of 31,895 ckm of transmission lines and transformation capacity of 2,16,840 MVA at estimated cost of Rs 1,24,148 Cr. is expected to be added in the grid.

The Inter-Regional (IR) transmission capacity is expected to grow from present level of 1,12,250MW to about 1,18,740MW in next 2-3 years. Due to diurnal and seasonal variation in RE generation, power flow on all IR corridors except ER→SR, is observed in both directions. Maximum change is observed in WR→NR corridor, where power of the order of 24GW is flowing from WR to NR in Summer evening peak scenario and power of the order of 20GW is flowing from NR to WR in Winter solar max scenario. New high capacity links in WR-SR, WR-NR, and WR-ER corridors are under various stages of planning or approval to cater to increased inter-regional power transfer.

Chapter-4 to **Chapter-8** are dedicated to detailed study results pertaining to each of the five regions, i.e. one Chapter for each Region. State wise LGBs have been prepared for all the regional grids for nine load-generation scenarios and outcomes of study results have been brought out. Critically loaded lines & transformers under normal & N-1 condition, voltage violations, short circuit violations etc. have been reported in both ISTS and STU network and possible reasons/cause for the same are also brought out in respective regional chapters. Further, detailed scope of works and implementation time-frame along with schematic of new ISTS schemes including schemes for RE evacuation for mitigating some of these violations have been brought out in these Chapters. For remaining violations, additional expansion schemes in ISTS are being planned after detailed studies, and accordingly the details of the same would be brought out in the subsequent Rolling Plan reports.

India being centrally places in South Asia is playing a vital role in establishment of interconnections between countries so as to establish a large South Asian electricity grid. In **Chapter-9**, details on existing, under-construction and under discussion cross-border interconnections between India and neighbouring countries have been brought out.

The summary of the studies carried out, new expansion schemes planned, way forward etc. have been mentioned in **Chapter-10**.

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Chapter 1: Background and Objective

India being an emerging-developing nation is ought to see the largest increase in energy demand in the years to come. Energy use has already been doubled since 2000, with 80% of demand still being met by conventional sources. In order to meet the increasing demand for electricity in the country, massive addition to the installed generating capacity is required. India's power sector is one of the most diversified in the world as sources of power generation range from conventional sources such as coal, lignite, natural gas, oil, hydro and nuclear to viable non-conventional sources such as wind, solar and agricultural & domestic waste.

Sustainable development being the need of the hour is emphasised around the world. In this regard, India is willing to increase the contribution of generation from renewable energy in the power sector. As committed in COP26, India will have total installed capacity of renewable of 500 GW by the year 2030 and about 225 GW RE (Solar & Wind) is expected to be integrated into the grid by 2026-27. Unlike conventional resources, renewable energy resources never run out and also contributes to negligible carbon emission that too at much cheaper cost. Despite so many pros, the large amount of integration of RE with grid comes with many challenges like low-capacity utilization factor (CUF), flexibility, intermittency etc. One of the solutions could be to implement energy storage systems which can store the excess electricity during off-peak period, moreover this can reduce the capex investment in transmission line if deployed smartly. Thus, network shall be planned in a manner that offers optimum techno-economical solution considering all the aspects without compromising the security, reliability and robustness of National Grid.

In this direction, Ministry of Power vide gazette notification dated 01st Oct 2021, has notified Electricity (Transmission System Planning, Development and recovery of Inter-State Transmission Charges) Rules, 2021. As per the said rules, CTU has to draw up plan for Inter-State Transmission System (ISTS) for up to next five years on rolling basis every year identifying specific transmission projects which are required to be taken up along with their implementation time lines. Accordingly, an ISTS planning procedure has been prepared and published by CTU in Dec'21 for the purpose of planning and coordination relating to ISTS.

As per the said ISTS Planning procedure, the entire process for transmission planning on rolling basis has been decided to be undertaken on continuous basis, involving two cycles i.e., from April to September and October to March. Thus, Rolling Plan reports would be brought out by CTU on half-yearly basis in the months of September and March every financial year. In this direction, a report on Network Plan 2024-25 has already been brought out on 31st Dec 2021 and the same is available on CTU website. This ISTS Rolling Plan report is being brought out wherein transmission system adequacy in ISTS has been ascertained for 2026-27 time-frame. This report covers year wise ISTS requirement on pan India basis to integrate the RE generation and also cater to the growing demand. To analyse the same, detailed studies including load flow, contingency analysis, voltage profile (reactive power management), short circuit studies etc have been carried out on all India basis for 2026-27 timeframe for nine perspective load-generation scenarios covering three seasons and three point on load curve (Solar max, evening peak and night off peak) of each season.

Counteractive measures for some of the identified issues in ISTS have been suggested in this report. However, ISTS planning being a continuous exercise, detailed studies are being carried out and new transmission elements, as required, would be planned to address the remaining issues. Details in this regard would be brought out in the next Rolling plan report to be published in September 2022.

Chapter 2: Power Supply Scenario

India's power demand has substantially increased from 136 GW at the end of 2013-14 to 203 GW as on Jan'22, a growth of about 49%. As per the 19th EPS published by CEA, this demand is expected to further increase to about 299 GW by 2026-27, which translates to growth by about 47%. To meet this fast-growing demand, generation capacity is also being continuously added into the grid. The installed capacity of India at the end of 2013-14 was about 243 GW which increased to about 395 GW as on Jan'22, a growth of about 63%. Installed Capacity is further expected to be about 568 GW by 2026-27 thereby registering a growth of about 44%. Furthermore, presently RES excluding hydro generation is contributing around 106 GW (27% of installed capacity) which will increase to around 225 GW (40% of installed capacity) by 2026-27, a growth of 112%.

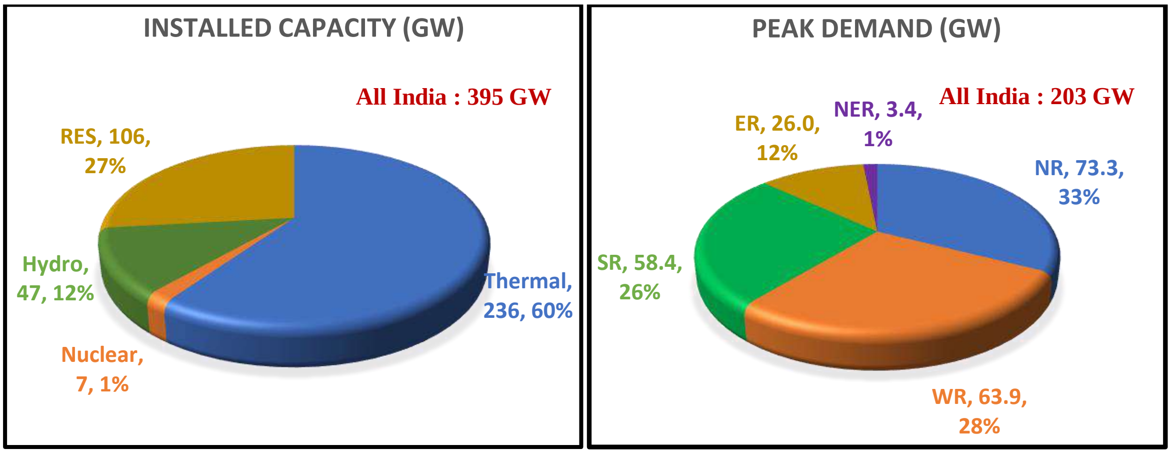
2.1 Present Power Supply Scenario

The total installed capacity as on Jan'22 was about 395 GW and the peak demand was about 203 GW. The region-wise breakup for the total installed capacity and peak demand on Jan'22 is given in the Table 2-1 & Figure 2-1.

Table 2-1: Installed Capacity and Peak Demand as on Jan'22

Region	Generation (GW)								Demand (GW)
	Thermal				Nuclear	Hydro	RES	Total	
	Coal	*Lignite*	*Gas*	*Diesel*					
NR	56.19	1.58	5.78	0.00	1.62	20.43	24.78	110.39	73.31
WR	73.59	1.40	10.81	0.00	1.84	7.56	32.51	127.71	63.87
SR	45.70	3.64	6.49	0.43	3.32	11.82	46.37	117.78	58.43
ER	27.65	0.00	0.10	0.00	0.00	4.75	1.72	34.22	26.02
NER	0.77	0.00	1.72	0.04	0.00	1.94	0.42	4.89	3.42
All India	**203.90**	**6.62**	**24.90**	**0.47**	**6.78**	**46.51**	**105.82**	**394.99**	**203.01**

Figure 2-1: Installed Capacity and Peak Demand as on Jan'22



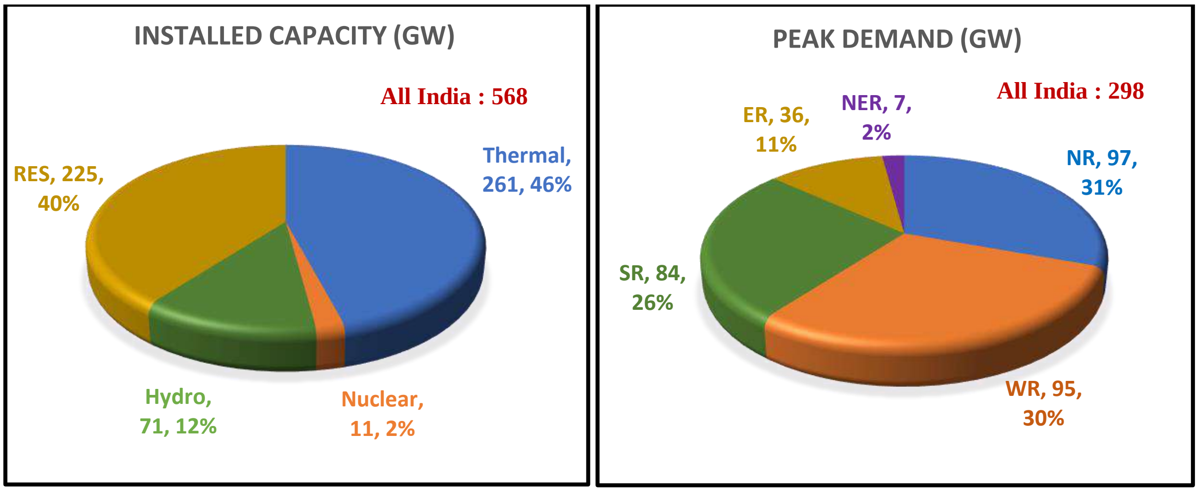
2.2 Envisaged Power Supply Scenario

As per the 19th EPS, all India peak demand for 2026-27 is expected to increase to 299 GW. To meet this increase in demand of about 95 GW from present, net 173 GW generation is envisaged to be added after considering the retirement of 15 GW of thermal generation by 2027. Details regarding the same are attached at **Annex-2.1**. Total installed capacity for 2027 shall be about 568 GW. The region-wise breakup for the installed capacity and projected peak demand for 2026-27 are tabulated in Table 2-2 & Figure 2-2:

Table 2-2: Projected Installed Capacity & Peak Demand by Mar'27

Region	Generation (GW)								Demand (GW)
	Thermal			Diesel	Nuclear	Hydro	RES	Total	
	Central	*State*	*IPP*						
NR	11.44	41.30	0.00	3.58	4.42	26.17	82.35	169.26	97.18
WR	19.00	35.95	36.85	10.14	3.24	8.17	70.44	183.78	94.82
SR	12.87	37.51	4.64	3.37	3.82	17.70	70.44	150.35	83.65
ER	24.44	12.78	4.15	0.00	0.00	14.69	1.50	57.55	35.67
NER	0.75	0.00	0.00	1.85	0.00	4.38	0.20	7.18	6.71
All India	**68.50**	**127.53**	**45.64**	**18.94**	**11.48**	**71.10**	**224.9**	**568.12**	**298.77**

Figure 2-2:Projected Installed Capacity & Peak Demand by Mar'27



The region wise growth in demand and fuel type wise increase in installed generation capacity for 2026-27 from present time-frame is tabulated below in Table 2-3.

Table 2-3:Peak demand & Generation IC in 2021-22 and 2026-27

Peak Demand (GW)				
	2021-22	***2026-27***	***Diff***	***% Increase***
NR	73.30	97.18	23.88	33%
WR	63.87	94.82	30.95	48%
SR	58.43	83.65	25.22	43%
ER	26.00	35.67	9.67	37%
NER	3.42	6.71	3.29	96%
All India	**203.00**	**298.77**	**95.77**	**47%**

Generation IC (GW)				
	Present	***2026-27***	***Diff***	***% Change***
Thermal	210.52	241.67	31.16	15%
Gas	24.90	18.94	-5.96	-24%
Nuclear	6.78	11.48	4.70	69%
Hydro	46.51	71.10	24.59	53%
Solar	50.30	152.27	101.97	203%
Other RE	55.52	72.65	17.14	31%
Total	**394.52**	**568.12**	**173.60**	**44%**

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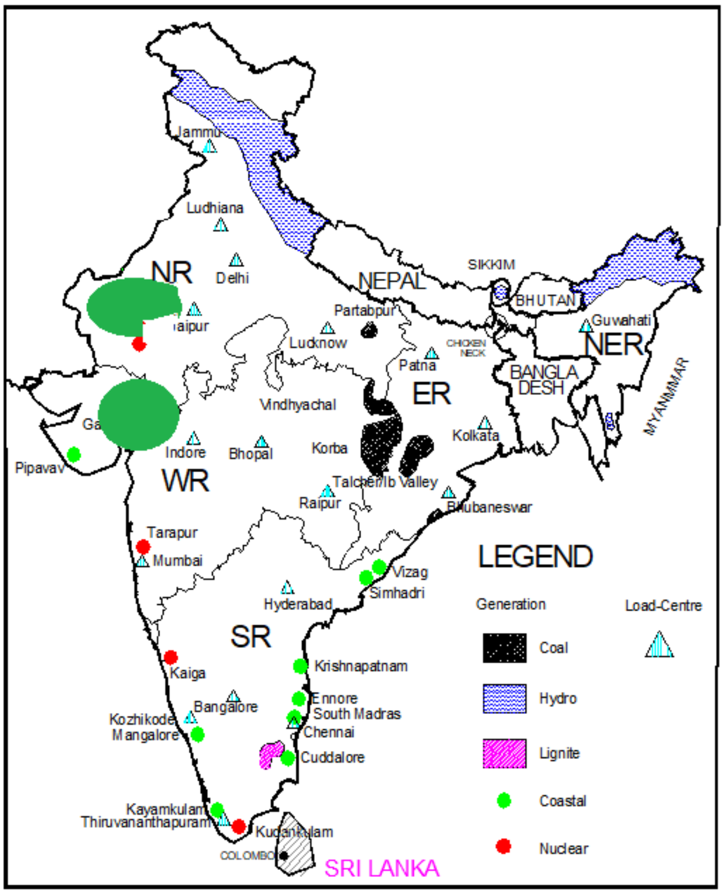
Chapter 3: All India Analysis

Installed Capacity mix of India is continuously changing with integration of renewable energy plants and in the future renewable generation installed capacity is going to share more and more portion of the total installed capacity. To plan transmission network for meeting electricity requirement of the country, first it is important to understand the locations of generation pockets and load centre in wide Indian demography. Most of the conventional thermal generation are located in eastern part of the India, whereas new generation addition in the form of renewable energy is coming up in Northern, Western and Southern Part of India as depicted in Figure 3-1. To meet demand of country from conventional generation, strong backbone transmission system is already planned and implemented in past decade. With the advent of renewable energy generation addition mostly in Western and Southern Part of India, power flow pattern on existing transmission system are changing. It becomes important to understand diurnal and seasonal regional exchanges taking place depending upon the generation and demand of a region and plan any additional transmission system to cater the requirement keeping all India perspective in mind.

Figure 3-1: India's map showing various generations in different parts of the country



The present study has been carried out to identify adequacy of existing, approved and planned transmission systems to meet the power transfer requirement till the timeframe of 2026-27 with an all India perspective, highlight the challenges if any and possible solution to carry out periodic assessment of transmission requirement under ISTS. Here it is to mention that substantial solar generation capacity addition has been envisaged in future which shall only generate in day time. A region having a high solar installed capacity shall become exporter of power during the afternoon and importer of the power during evening.

To study such phenomenon and analyses, power flow patterns in transmission network under various scenarios were identified. Accordingly, nine load generation balance scenarios were prepared corresponding to Monsoon, Summer and Winter season along with three points on daily load curve for each season. Details about the same are discussed in next section.

3.1 Load Generation Balance

To replicate and simulate seasonal power requirement variations on annual basis, three load-generation scenarios within a day in three different seasons were chosen. Three points on load curves were identified for each day i.e. Solar max (afternoon), Peak load (evening) and Off-peak load (night). Further, the same was carried out for three seasons viz. Monsoon (August), Summer (June) and Winter (February). Accordingly, load generation has been prepared for following nine scenarios:

- Aug'26: Solar max (Scenario-1), Evening Peak (Scenario-2) and Night off-peak (Scenario-3)
- Jun'26: Solar max (Scenario-4), Evening Peak (Scenario-5) and Night off-peak (Scenario-6)
- Feb'27: Solar max (Scenario-7), Evening Peak (Scenario-8) and Night off-peak (Scenario-9)

During afternoon hours, solar generation is at its peak and thermal generation requirement is minimal. While in evening, solar generation is zero and the thermal generation requirement is maximum. Load Generation Balance (LGB) for above mentioned nine scenarios considered for the study was prepared, (based on the discussions held on 11.03.2021 among CEA and POSOCO). To prepare load generation balance, details about the selection of points on load curve and generation despatching philosophies are discussed subsequently.

As per 19th EPS, All India peak demand is expected to be about 299 GW in 2026-27. To find out variation of this demand for nine scenarios, demand pattern of year 2019-20 for the three representative months was analysed and three points on the average demand curve of three months corresponding to solar max, evening peak and night off peak were selected, which are depicted in Figure 3-2, Figure 3-3 & Figure 3-4 below. Demand data of 2020-21 was not considered for above analysis due to impact of COVID epidemic.

Figure 3-2:Summer (June'19) Load Curve

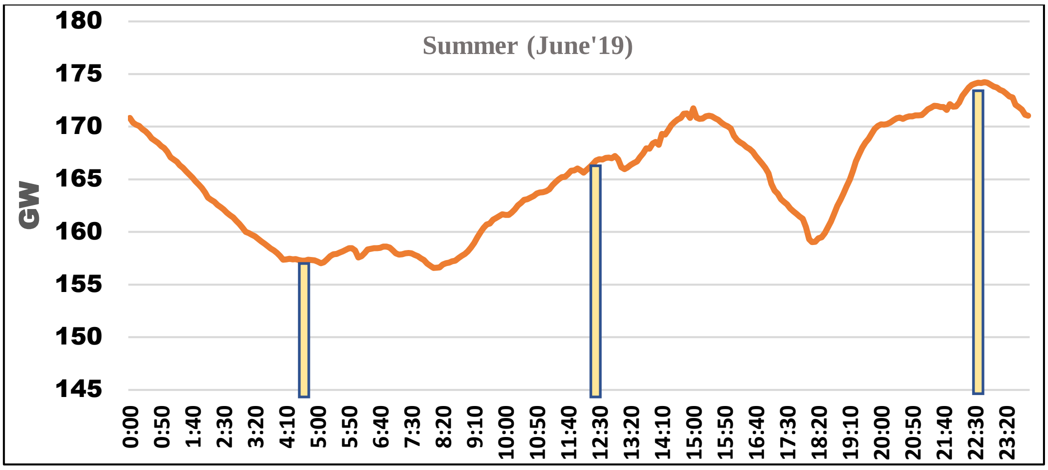


Figure 3-3: Monsoon (Aug'19) Load Curve

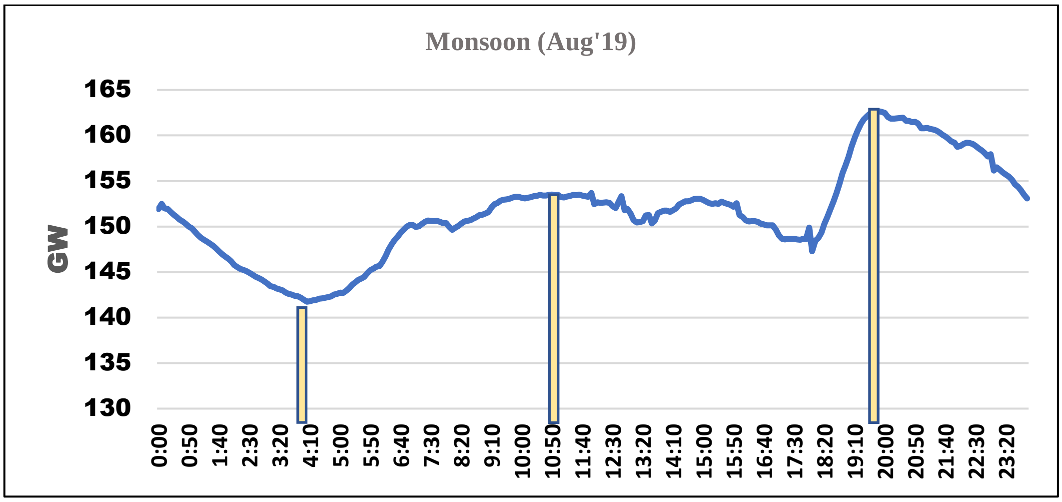
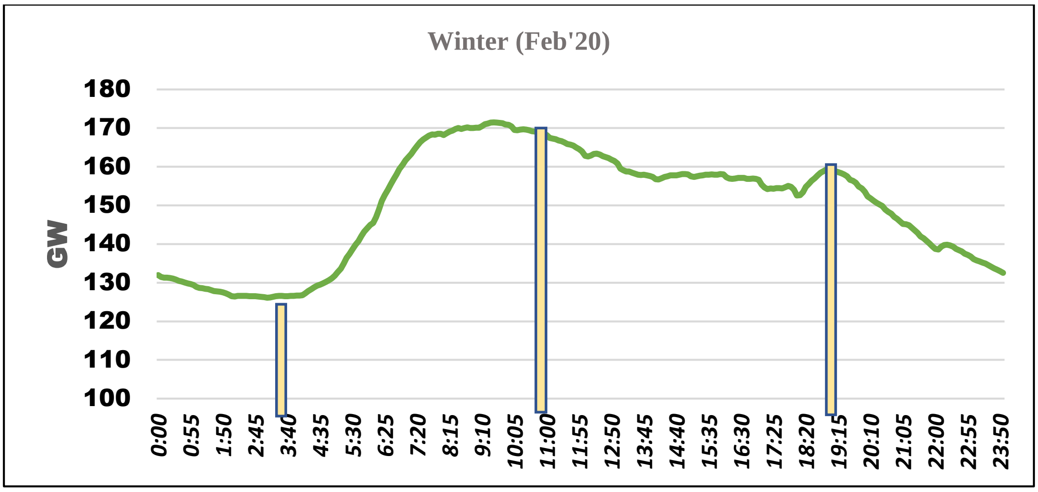
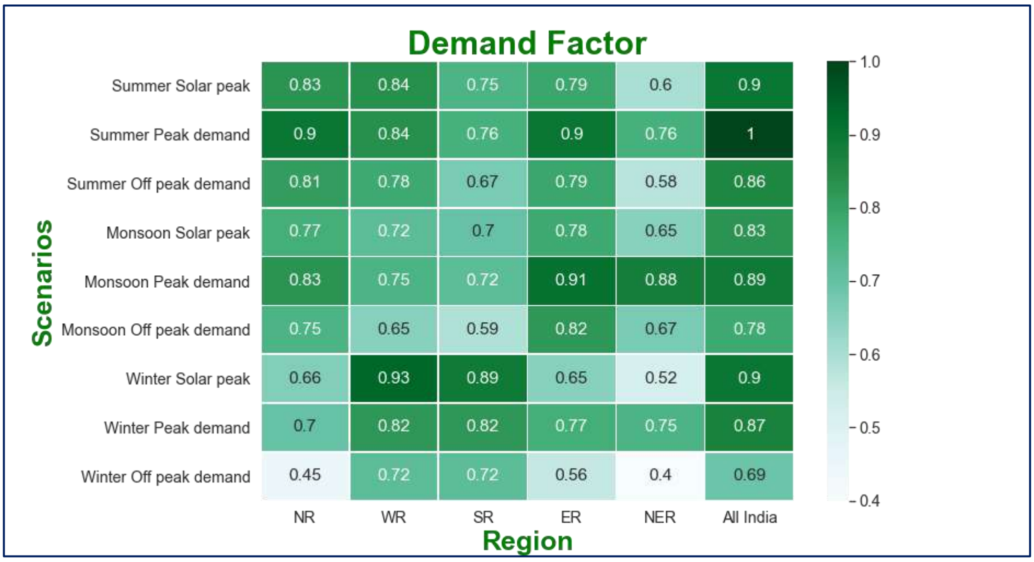


Figure 3-4:Winter (Feb'20) Load Curve



Demand corresponding to these points was divided by maximum All India/regional demand of the corresponding year to obtain the demand factors. The same has been used for calculating All India/regional demand for different scenarios of 2026-27 time-frame as shown in Figure 3-5.

Figure 3-5:Demand factors considered for 2026-27-time frame



To meet the anticipated demand in different scenarios, various sources of generations viz. Thermal, Nuclear, Hydro, Gas, Solar, Wind are available. However, despatch of some of these generators shall be as per their diurnal and seasonal variation. For this purpose, region wise load generation balancing philosophy was considered for the study. Each generation except thermal generation in a region was despatched as per the despatch factors considered in regional chapters.

RE has been considered as must-run, at first the demand was balanced by RE generation. Since all utilities have RE RPO obligation, total RE generation has been apportioned as per RE RPO to all regions based on their projected EPS demand. Further, for accounting the availability of solar roof-top generation, equivalent demand was reduced from respective regions. After determining the demand met by renewable energy, nuclear and hydro generation, remaining demand was met by Thermal.

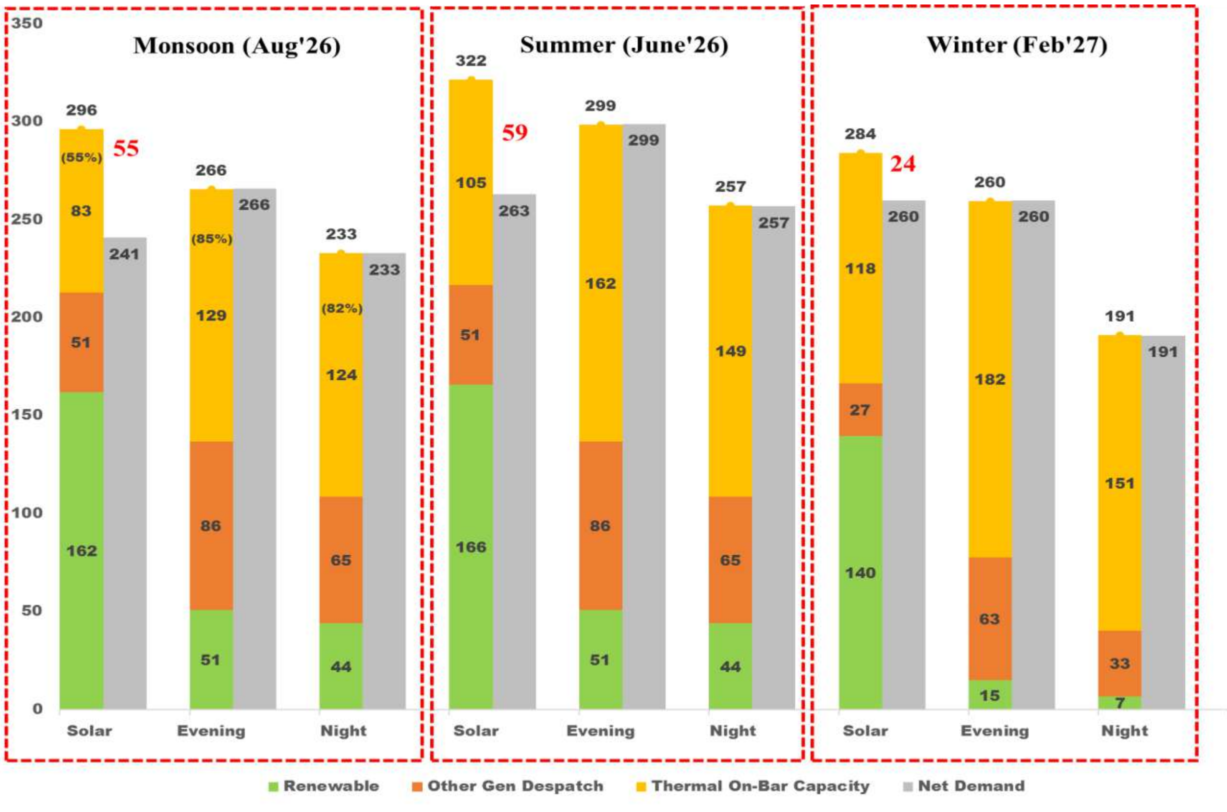
Evening peak scenario of each month was setup first as the number of thermal units required on bar shall be maximum. Total thermal generation requirement for the evening peak scenario was apportioned between State and Central sector thermal generations as per their installed capacity in each region. Further, state thermal generation requirement was divided among the states as per their maximum demand in respective month of 2019-20. After obtaining state thermal generation requirement, thermal units were dispatched at technical maximum (85%) in merit order for each state.

ISGS, CGS & IPP thermal plants with lower variable cost were dispatched at technical maximum (85%) region wise progressively. To meet the demand of any deficit region thermal generation dispatches from other regions considering all India merit order for evening peak scenario was considered. For night off-peak scenario, on bar thermal units were scaled down proportionately.

While preparing the present LGB for Solar max scenario, some plants were switched off to balance the load generation while running all the on-bar thermal plants at technical minimum of 55%. Accordingly, thermal plants with higher cost (on merit order basis) were switched off region wise progressively till the LGB is balanced.

It is observed that in the Solar max scenario there is surplus power available in the grid. It is due to availability of peak solar generation and lesser demand in the noon. This surplus is on account of keeping the same number of thermal plants operating at technical minimum (55%) in Solar max scenario which are required to meet evening peak demand. Even after considering the flexibility exhibited by gas and hydro generation between the evening peak and Solar max scenario the surplus generation in terms of GW dispatches is given in Figure 3-6 below.

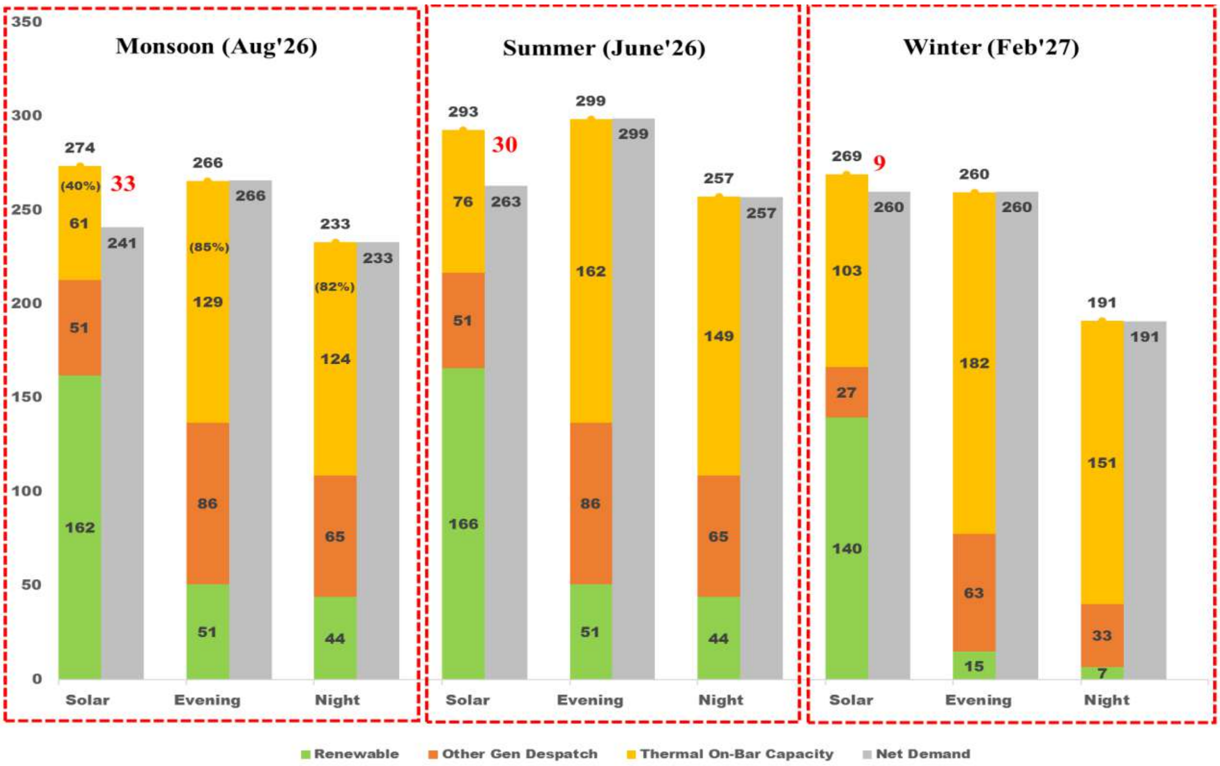
Figure 3-6:Generation surplus with Tech Min (55%) for Thermal Units



It may be observed that surplus generation of 55 GW, 59 GW, and 24 GW during Solar max in Monsoon, Summer, and Winter season respectively is available which needs to be stored using energy storage and consumed in other hours of the same day.

A sensitivity analysis is done to check the quantum of surplus generation, if thermal units are backed down to 40% of their capacity and the corresponding results are given in Figure 3-7 below:

Figure 3-7:Generation surplus with Tech Min (40%) for Thermal Units



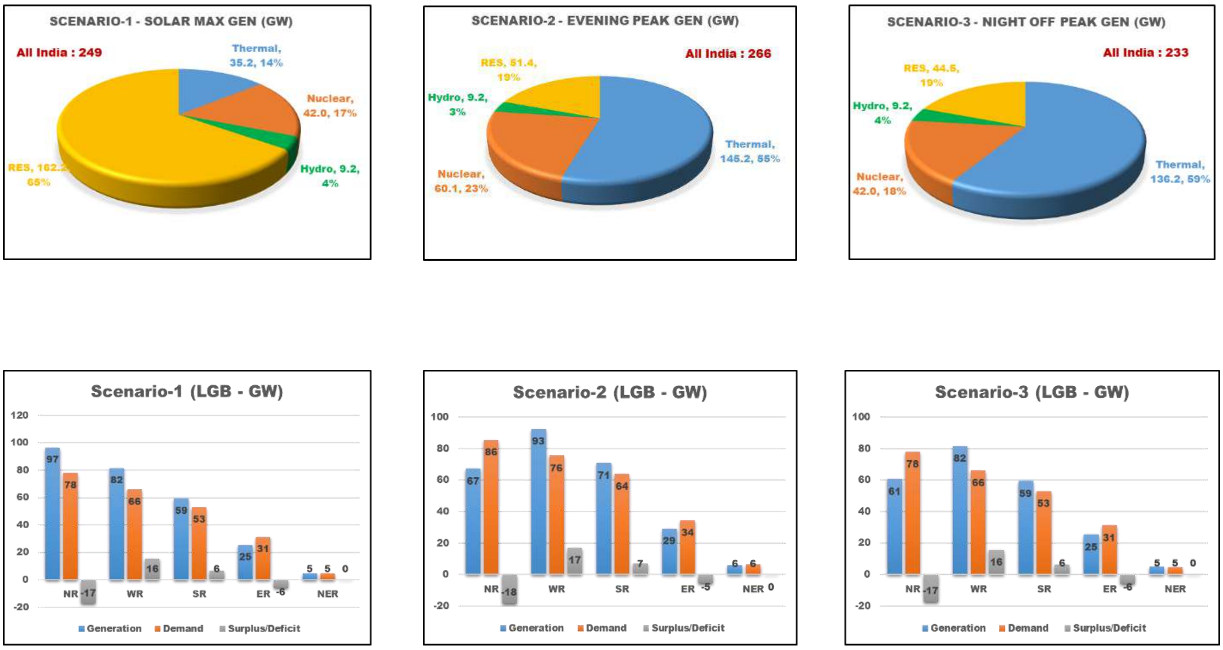
Even after backing down thermal units to 40%, surplus generation of the order of 33 GW, 30 GW and 9 GW are observed during Solar max in Monsoon, Summer and winter seasons respectively. Thus, energy storage system of about 33 GW capacity may be required to be installed in the grid to facilitate integration of about 225 GW of RE. In case, energy storage system not installed adequately and if the number of on bar thermal units are to be kept same throughout the day during 2026-27, then thermal unit may need to be backed down to 19% to 20% during Solar max scenario in Monsoon and Summer respectively, which may not be practically feasible.

Based on above philosophy, LGB prepared for different scenarios are depicted in Figure 3-8, Figure 3-9, Figure 3-10 and details about the same are attached at **Annex 2.2.**

Out of these nine scenarios, Scenario-5(June'26 evening peak) and Scenario-9 (Feb'27 Night off peak) corresponds to two extreme cases with respect to demand i.e., highest demand (299 GW) and lowest demand (191 GW) scenarios respectively. In all other scenarios, all India demand is varying between these two demands as per demand factors. Further Scenario-1 corresponds to maximum RE generation share to meet the demand of that scenario. Based on LGB, region wise surplus/deficit in each scenario is summarised in Table 3-1. Furthermore, both maximum surplus and deficit of each region is highlighted too in Table 3-1.

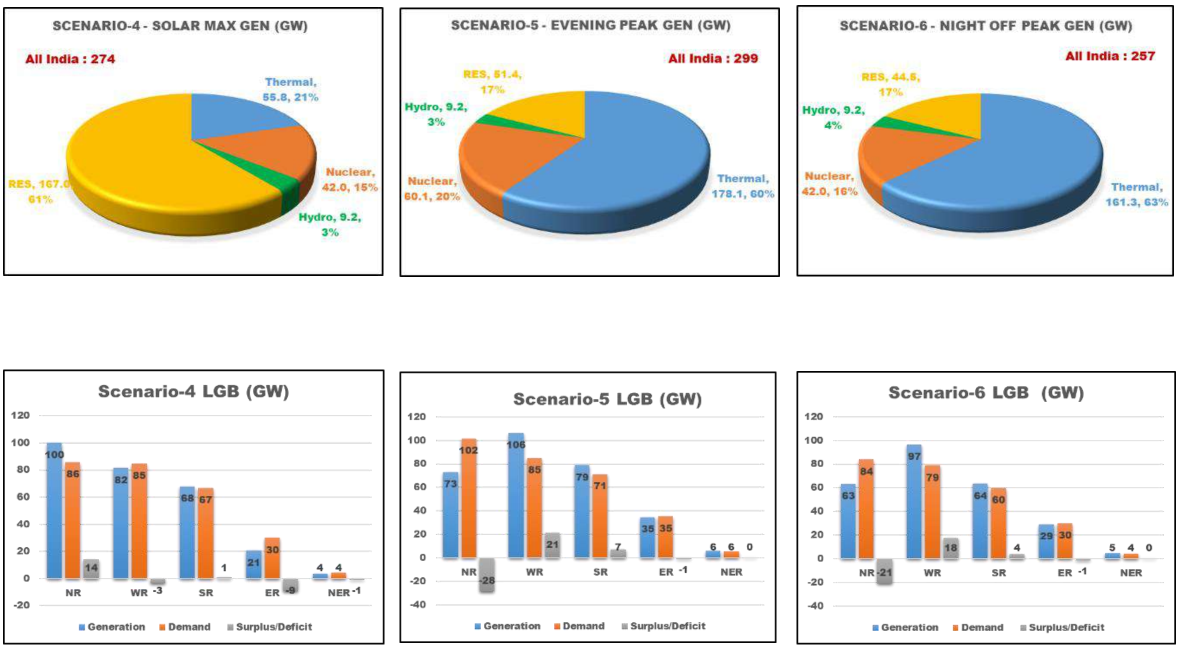
Monsoon Aug’2026

Figure 3-8:LGB for Monsoon Aug'2026



Summer June’2026

Figure 3-9: LGB for Summer June'2026



Winter Feb'2027

Figure 3-10:LGB for Winter Feb'2027

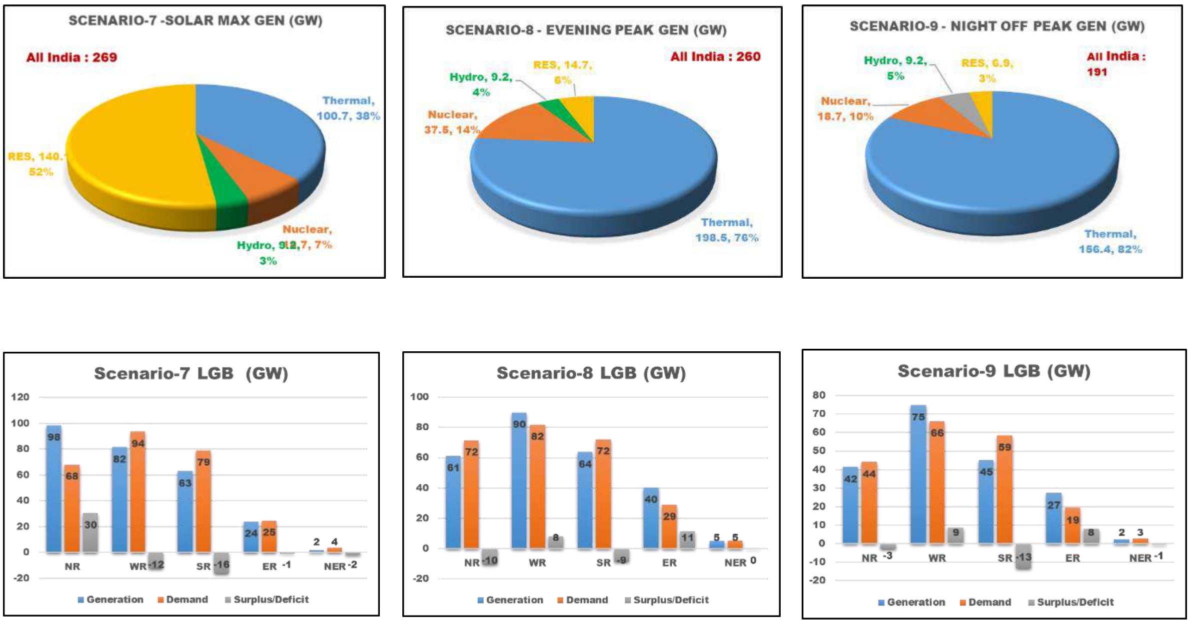


Table 3-1:Regional Surplus/Deficit summary in MW

Surplus (+) / Deficit (-)	Aug'26 (Monsoon)			Jun'26 (Summer)			Feb'27 (Winter)		
Scenario No. / Region	1 Solar Max	2 Peak Load	3 Off Peak	4 Solar Max	5 Peak Load	6 Off Peak	7 Solar Max	8 Peak Load	9 Off Peak
NR	17317	-18302	-17347	14106	**-28391**	-20707	**30445**	-10390	-2738
WR	-2053	17079	15612	-3278	**21428**	17606	**-12060**	7989	8598
SR	-1263	6922	6477	1228	**7441**	3700	**-16002**	-8521	-13337
ER	**-12370**	-5354	-5948	-9270	-824	-1034	-746	**11383**	8040
NER	-1020	-346	91	-668	345	**434**	**-1827**	-461	-563

From the above table it may be inferred that:

- NR is importing as well as exporting power in different scenarios. Export of power is taking place in solar max scenarios due to high solar generation in NR, whereas maximum import of power is happening in Summer (June) evening peak load scenario.
- WR generally exports the power with a maximum export of 21 GW in Summer (June) evening peak scenario. Due to low availability of RE during Winter (Feb), WR becomes deficit to the tune of 12 GW.
- SR is importing as well as exporting power under various scenarios. Maximum export of power is 7 GW in Monsoon (August) evening peak scenario due to high wind generation in monsoon season, whereas maximum import of the order of 16 GW is taking place in the Winter (February) Solar max case due to very low wind generation at that time.